'A'

DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH
RESIDENT REPRESENTATIVE
UNIVERSITY OF WASHINGTON
410 UNIVERSITY DISTRICT BUILDING
1107 N.E. 45TH STREET
SEATTLE, WA 98105-4631

IN REPLY REFER TO:

AD-A246 014

425:RJS:ead
N00014-88-K-0113
15 January 19921

From: Office of Naval Research Resident Representative, Seattle
To: ONR Scientific Officer, Dr. Edwin P. Rood, Code 1132F, Mechanics Division, Office of the Chief of Naval Research, Ballston Tower # 1, 800 North Quincy Street, Arlington, VA 22217-5000

Subj: REQUEST FOR FINAL TECHNICAL APPROVAL, CONTRACT N00014-88-K-0113; R&T PROJECT CODE: 4322804---06; THE UNIVERSITY OF IOWA; PRINCIPAL INVESTIGATOR IS PROFESSOR FREDRICK STERN, INSITITUTE OF HYDRAULIC RESEARCH

1. This office is in the process of closing subject contract. We have been advised that the final technical report has been submitted.

2. So that closeout may continue, please provide this office with information as to whether technical requirements have been performed satisfactorily.

Eleanor A. Dixon
ELEANOR A. DIXON
Procurement Assistant

cc:
DTIC (w/copy of final technical report)
****************************** DO NOT DETACH ********************************

FIRST ENDORSEMENT on ONR ltr., dtd. 15 January 1992

From: ONR Scientific Officer, Dr. Edwin P. Rood, Code 1132F

To: Office of Naval Research, Seattle

1. Returned for necessary action.

2. I certify that all technical requirements under subject contract are:

____ Satisfactory

____ Unsatisfactory

____ Comments:

92-01823

92 1 22 057

Date

Scientific Officer

THE UNIVERSITY OF IOWA

COPY

10 January 1992

Dr. E.P. Rood
Scientific Officer, Hydrodynamics
Office of Naval Research
800 North Quincy Street
Arlington, Virginia 22217

Dear Dr. Rood:

Free-Surface Effects on Ship Boundary Layers and Wakes
ONR Contract N00014-88-K-0113
Final Technical Report

This is the Final Technical Report on the above referenced research project through 31 December 1991. Future related research will be reported under the recently initiated contract renewal under ONR Grant N00014-92-J-1092.

1. Foil-Plate Model Experiments

The report and journal article describing the wake experiments, including comparisons with the calculations, has been completed (Stern et al., 1991).

A new experimental program has been planned, which will focus on the detailed resolution and determination of the fundamental physical mechanisms of the flow in the neighborhood of the body/free-surface boundary layer and wake (i.e., the solid-fluid juncture and wake regions). Both mean and turbulence velocities will be measured for zero, medium, and large steepness. Also, an effort will be made to measure the wave-induced separation flow pattern. The experiments require a substantial upgrade of the IIHR towing tank, including the following: two-component LDV system designed specifically for the present project, which utilizes a streamlined fiber-optic probe and an automated traversing system; complete rebuilding of the towing-tank trailer in order to house the LDV system; rewiring of the towing tank to provide the necessary power requirements of the LDV system; and complete refurbishing of the foil-plate model. The total cost involved is about $200 K. Presently, most of the issues pertaining to the upgrade have been resolved. We hope to complete the upgrade and initiate the experiments in about six months.

2. Series 60 C_B = .6 Ship Model Experiments

The report and journal article describing the mean-flow measurements in the boundary layer and wake and wave field for Fr = .16 and .316 has been completed (Toda et al., 1991). The journal article describing the scale-effect studies has also been completed (Longo et al., 19991).

Institute of Hydraulic Research   Iowa City, Iowa 52242 U.S.A.   Phone: 319/335-5237   Telex: 756569   FAX: 319/335-5238   Bitnet ID: AEGCRAPAQUIAMVS

A

The local wave-elevation measurements have been completed for 5 and 10 deg yaw angle and Fr = .16 and .316. Typical results are shown in figure 1, which are considered satisfactory and dramatically underscore the complex nature of the wave field for the yawed condition. Presently, comparisons are being made between the data and inviscid-flow calculations. Also, the detailed mean-velocity and pressure field measurements are being initiated for the 10 deg yaw condition.

3. Development of the Computational Method

During the present contract period, our efforts have been directed in the following areas: (a) calculations for the Stokes-wave/flat-plate flow field; (b) development of interactive and large-domain approaches for calculating ship boundary layers and wakes for nonzero Fr; and (c) extensions of the interactive approach for yawed-ship calculations. The results from these efforts are summarized below.

(a) Laminar-flow calculations are in progress concerning higher-order and exact treatments of the free-surface boundary conditions (fsbc) and detailed resolution of the flow in the region very close to the free surface in which the fsbc play an important role. Results for wave steepness Ak = .01 have been obtained utilizing a refined grid near the free surface and three alternative treatments of the fsbc: (1) zero-gradient conditions for both V and p; (2) zero-gradient conditions for V and an inviscid small-amplitude wave normal-stress condition for p; and (3) exact, i.e., viscous stress conditions for u, v, and p, continuity for w, and free-surface update through the kinematic fsbc.

Figure 2 provides a comparison of the relative error for the three treatments, including results in which the conditions are satisfied both on the mean and updated free surfaces. Clearly, the error is substantially reduced for the more exact treatments. Figures 3a,b provide an overview of certain aspects of the solutions through the velocity [$\Delta V = V(Ak = .01) - V(Ak = 0)$] and vorticity [$\Delta\omega = \omega(Ak = .01) - \omega(Ak = 0)$] differences for zero and nonzero steepness. The effects of the wave-induced pressure gradients are seen to propagate to depths of about $\lambda/2$ and primarily influence Δu, Δw, and $\Delta\omega_x$, and $\Delta\omega_z$. The effects of the fsbc are confined to a region very close to the free surface and primarily influence Δu, Δw, and $\Delta\omega$. In particular, the fsbc induce vorticity and vorticity interactions, as displayed in figures 4a,b,c, which display the convection, stretching/bending, and diffusion terms of the axial ω_x, transverse ω_y, and depthwise ω_z vorticity equations, respectively.

Presently, the solutions are being further analyzed to fully explicate the role of the fsbc and the interaction between the boundary-layer and wake vorticity, including wave-induced pressure gradient effects, and the vorticity induced by the fsbc and the free-surface boundary layer edge conditions. Also, calculations using exaggerated free-surface boundary-layer edge conditions and for larger wave steepness (i.e., Ak = .11) are in progress. An abstract for a proposed presentation describing this work has been submitted to the 1992 Free-Surface Vorticity Workshop (see item 4).

(b) Validation studies have been completed for the interactive approach through calculations for the Series 60 C_B = .6 ship model, including resolution of the bow flow and comparisons with the experimental data of Toda et al. (1991). The results are satisfactory and indicate that the interactive approach fully exploits the advantages of both the inviscid and viscous technologies and properly accounts for their interaction. Presently, a journal article is in preparation describing the calculations and comparisons (Tahara and Stern, 1992).

With regard to the development of a large-domain approach for the present problem two strategies for initiating the solution have been pursued: (1) based on the nonzero Fr inviscid solution; and (2) based on the zero Fr viscous solution. As discussed in the last Quarterly Progress Report dated 19 July 1991, satisfactory results were obtained using strategy (1) and both fixed and free-surface conforming grids. However, the strategy (2) is preferable since, in this case, the viscous solution is independent of the inviscid one. Calculations were made using strategy (2) and a fixed grid, but were found to be computationally unstable. Also, it was found that the wave field violated the radiation condition. Presently, an unsteady approach is under development in which the solution is initiated from a condition of zero freestream velocity and accelerated to a steady-state nonzero value. A laminar-flow code is under development for the initial calculations.

(c) Extensions are being made of the interactive approach for yawed-ship calculations. Figures 5 and 6 provide SPLASH results for the Series 60 C_B = .6 ship model for Fr = 0 and .316, respectively, and yaw angles ψ = 0, 5, and 10 deg. Both barebody and Fr = 0 displacement body results are shown. Presently, the results are being evaluated through comparisons with the experimental data.

Extensions are also in progress of the viscous-flow code for interactive nonzero Fr yawed-ship calculations. Initially, zero Fr calculations are being performed to validate the extensions. Large-domain calculations have been completed and are considered satisfactory (Van and Stern, 1991). Presently, extensions are being made to resolve the bow flow in conjunction with interactive calculations, first for Fr = 0, and then for nonzero Fr.

4. Interactions with Navy Agencies

1. In response to Dr. Rood's letter of 20 November 1991, an abstract has been submitted for a proposed presentation at the 1992 Free-Surface Vorticity Workshop entitled "Solid-Fluid Juncture Boundary Layer and Wake with Waves."

5. Publications

Longo, J., F. Stern, and Y. Toda, (1991), "Mean-Flow Measurements in the Boundary Layer and Wake and Wave Field of a Series 60 C_B = .6 Ship Model - Part 2: Scale-Effects on Near-Field Wave Patterns and Comparisons with Inviscid Theory," submitted to J. of Ship Research.

Stern, F., Choi, J. E., and Hwang, W.S., (1991), "Effects of Waves on the Wake of a Surface-Piercing Flat Plate: Experiment and Theory," Iowa Institute of Hydraulic Research, The University of Iowa, IIHR Report No. 353; also submitted to J. of Ship Research.

Tahara, Y. and Stern, F., (1992),"Validation of an Interactive Approach for Calculating Ship Boundary Layers and Wakes for Nonzero Froude Number," in preparation for submission to Computers and Fluids.

Toda, Y., Stern, F., and Longo, J., (1991), "Mean-Flow Measurements in the Boundary Layer and Wake and Wave Field of a Series 60 C_B = .6 Ship Model for Froude Numbers .16 and .316," Iowa Institute of Hydraulic Research, The University of Iowa, IIHR Report No. 352; also to appear in Proc. of The Second Osaka International Colloquium on Viscous Fluid Dynamics; also submitted to J. Ship Research under title "Mean-Flow

Measurements in the Boundary Layer and Wake and Wave Field of a Series 60 C_B = .6 Ship Model - Part 1: Froude Numbers .16 and .316."

Van, S.-H. and Stern, F., (1991), "Computation of Viscous Flows around Wigley Hull Advancing with an Angle of Attack," presented at the fall meeting SNAK.

6. Miscellaneous

1. Dr. Stern gave an invited presentation to the Partnership for Americas Cup Technology on 16 September entitled "Wave/Boundary-Layer and Wake Interaction."

2. Dr. Stern attended and gave a presentation (Toda et al., 1991) at The Second Osaka International Colloquium on Viscous Fluid Dynamics in Osaka, Japan on 27 through 30 September 1991. During this period Dr. Stern held meetings with Dr. Toda concerning the Osaka/IIHR cooperative project on propeller-hull interaction.

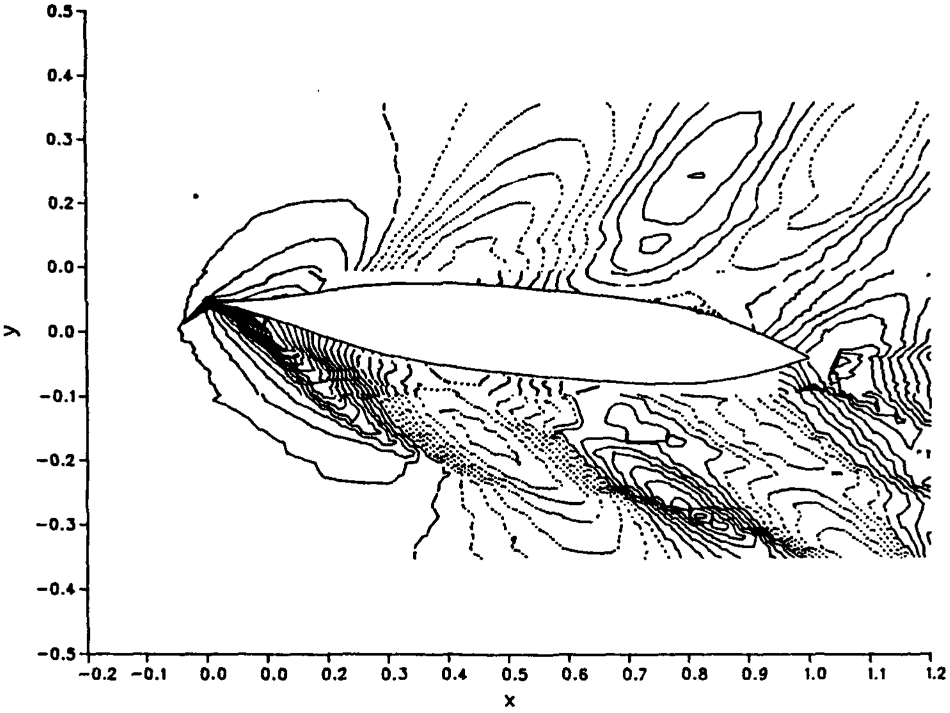
3. Dr. Stern visited, by invitation, CSSRC (Wuxi, China) and MARIC (Shanghai, China) and gave presentations entitled "Computational Fluid Dynamics," "Wave/Boundary-Layer and Wake Interaction," and "Viscous Propulsor Hydrodynamics."

4. A proposal was submitted for 300 hours of supercomputer time on the NAS system for FY 92 in support of future related research.

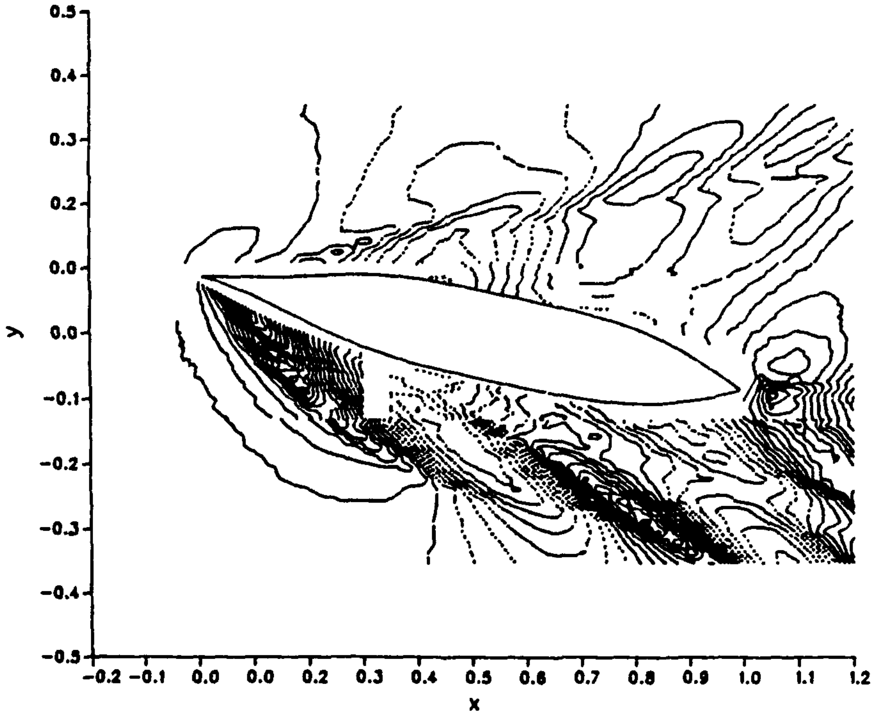
Respectfully submitted by,

Fred Stern
Principal Investigator

cc: Mr. Robert L. Silverman, ONR, Seattle

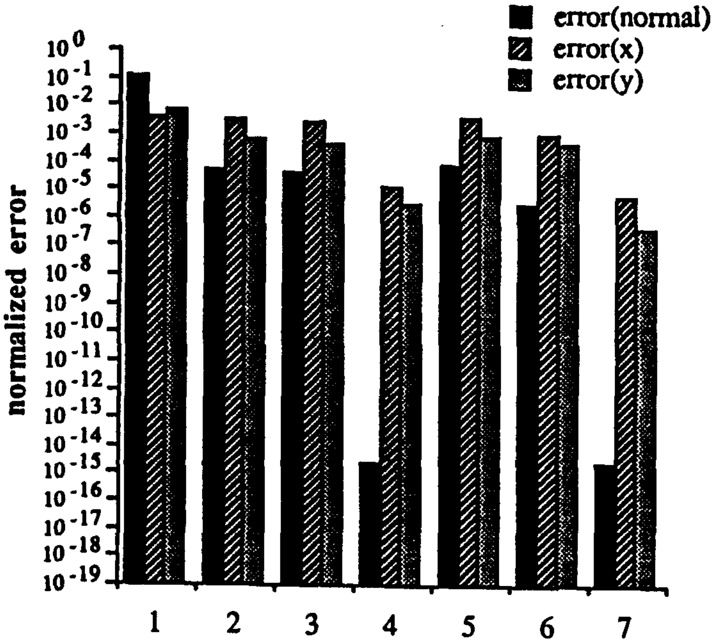


(a) 5 degree yaw



(b) 10 degree yaw

Figure 1 Wave-Elevation Contours



dynamic free-surface condition

1 zero gradient at $z = 0$

2 pressure w/o curvature effect at $z=0$

3 stress w/o curvature effect at $z=0$

4 exact at $z = 0$

5 pressure w/o curvature effect at $z=\eta$

6 stress w/o curvature effect at $z=\eta$

7 exact at $z = \eta$

$$\text{normalized error} = \sum_{i\,j\,=\,1}^{max} |\,\text{error}\,| \;/\; (\text{imax} * \text{jmax})$$

Free-surface conforming grid :

$$\text{error (x)} = -\frac{1}{Re}\left(\frac{\partial U}{\partial z} + \frac{\partial W}{\partial x}\right) - \eta_x\left(p + \frac{\eta}{Fr^2}\right) + 2\,\frac{\eta_x}{Re}\frac{\partial U}{\partial x} + \frac{\eta_y}{Re}\left(\frac{\partial U}{\partial y} + \frac{\partial V}{\partial x}\right)$$

$$\text{error (y)} = -\frac{1}{Re}\left(\frac{\partial V}{\partial z} + \frac{\partial W}{\partial y}\right) - \eta_y\left(p + \frac{\eta}{Fr^2}\right) + 2\,\frac{\eta_y}{Re}\frac{\partial V}{\partial y} + \frac{\eta_x}{Re}\left(\frac{\partial V}{\partial x} + \frac{\partial U}{\partial y}\right)$$

$$\text{error (normal)} = p + \frac{\eta}{Fr^2} - \frac{2}{Re}\frac{\partial W}{\partial z} + \frac{\eta_x}{Re}\left(\frac{\partial U}{\partial z} + \frac{\partial W}{\partial x}\right) + \frac{\eta_y}{Re}\left(\frac{\partial V}{\partial z} + \frac{\partial W}{\partial y}\right)$$

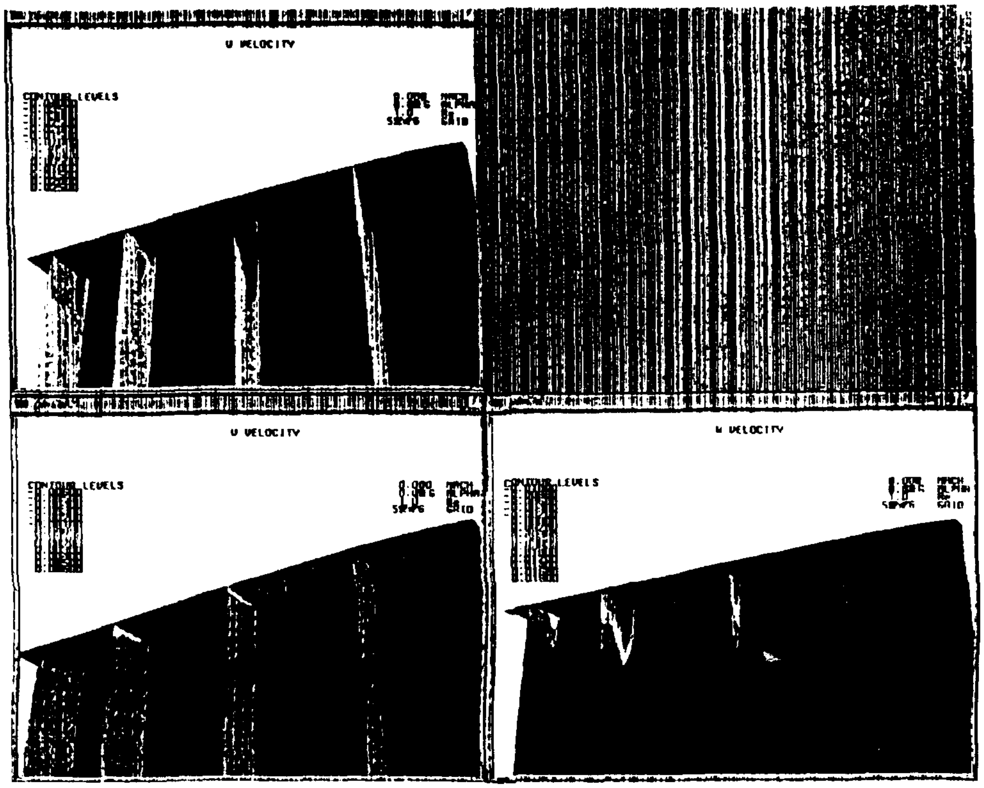
Mean free-surface grid :

$$\text{error (x)} = -\frac{1}{Re}\left(\frac{\partial U}{\partial z} + \frac{\partial W}{\partial x}\right) - \eta_x\left(p + \eta\frac{\partial p}{\partial z} + \frac{\eta}{Fr^2}\right) + 2\,\frac{\eta_x}{Re}\frac{\partial U}{\partial x} + \frac{\eta_y}{Re}\left(\frac{\partial U}{\partial y} + \frac{\partial V}{\partial x}\right)$$

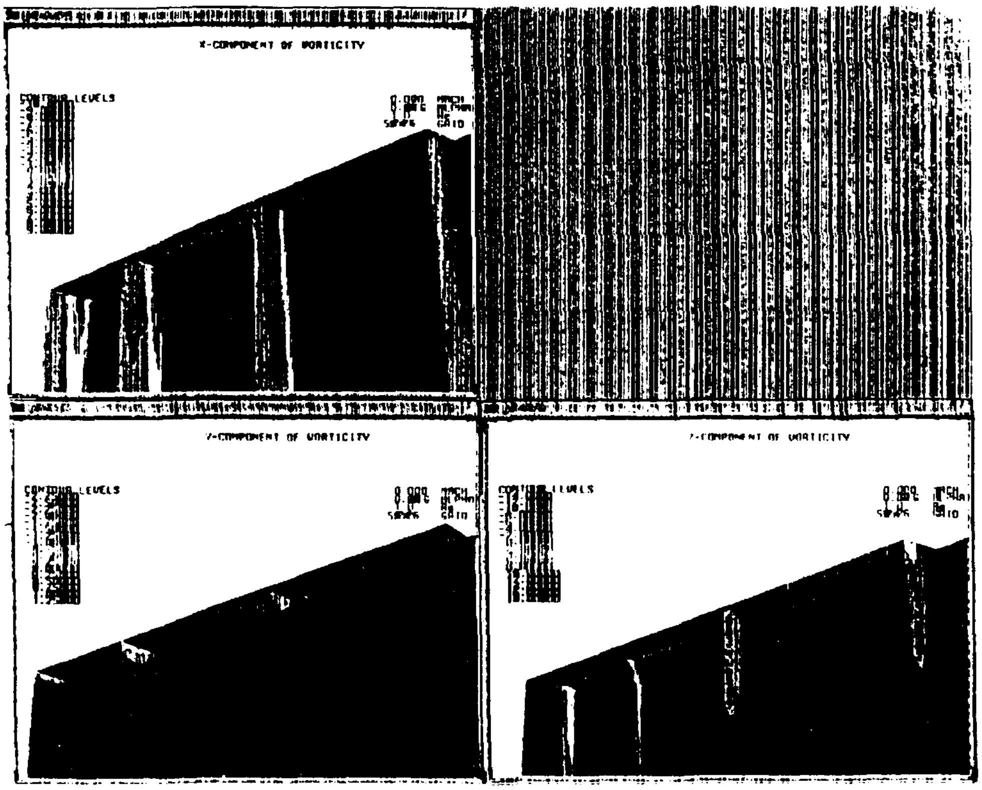
$$\text{error (y)} = -\frac{1}{Re}\left(\frac{\partial V}{\partial z} + \frac{\partial W}{\partial y}\right) - \eta_y\left(p + \eta\frac{\partial p}{\partial z} + \frac{\eta}{Fr^2}\right) + 2\,\frac{\eta_y}{Re}\frac{\partial V}{\partial y} + \frac{\eta_x}{Re}\left(\frac{\partial V}{\partial x} + \frac{\partial U}{\partial y}\right)$$

$$\text{error (normal)} = p + \eta\frac{\partial p}{\partial z} + \frac{\eta}{Fr^2} - \frac{2}{Re}\frac{\partial W}{\partial z} + \frac{\eta_x}{Re}\left(\frac{\partial U}{\partial z} + \frac{\partial W}{\partial x}\right) + \frac{\eta_y}{Re}\left(\frac{\partial V}{\partial z} + \frac{\partial W}{\partial y}\right)$$

Figure 2 Comparison of the Relative Error for Various treatments of the Free-Surface Boundary Conditions

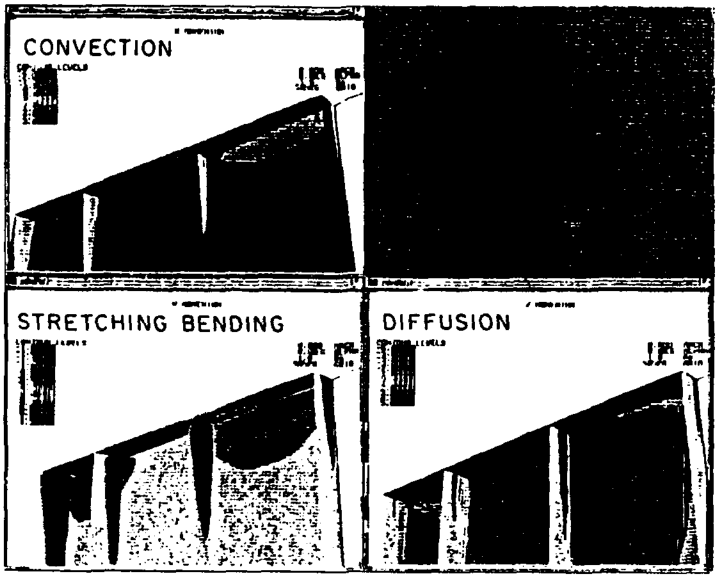


(a) velocity difference

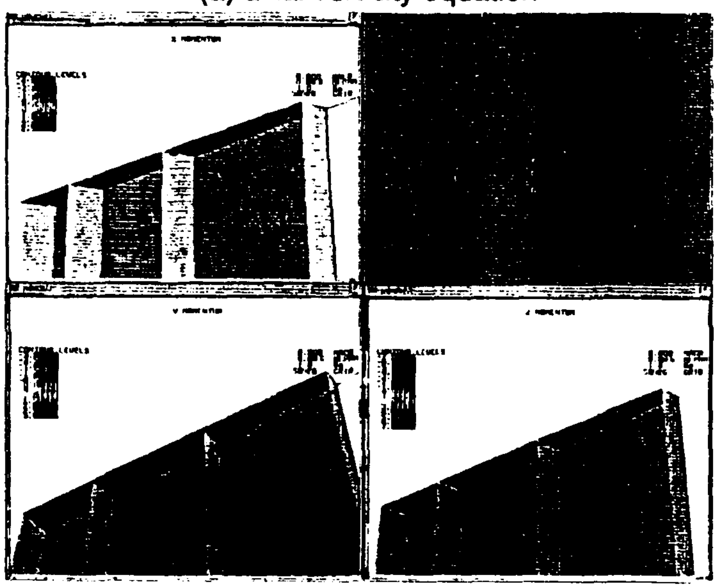


(b) vorticity difference

Figure 3 Difference Between Zero and Nonzero Steepness Solutions



(a) axial vorticity equation


(b) transverse vorticity equation

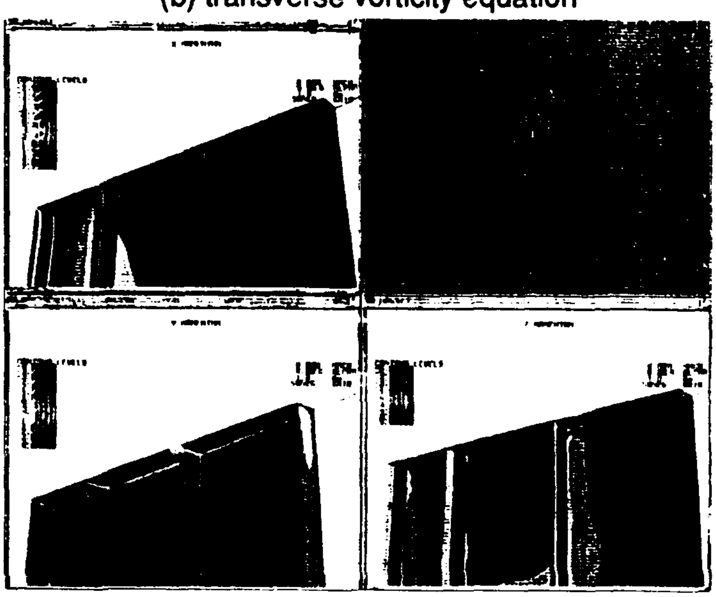

(c) depthwise vorticity equation

Figure 4 Vorticity Equation

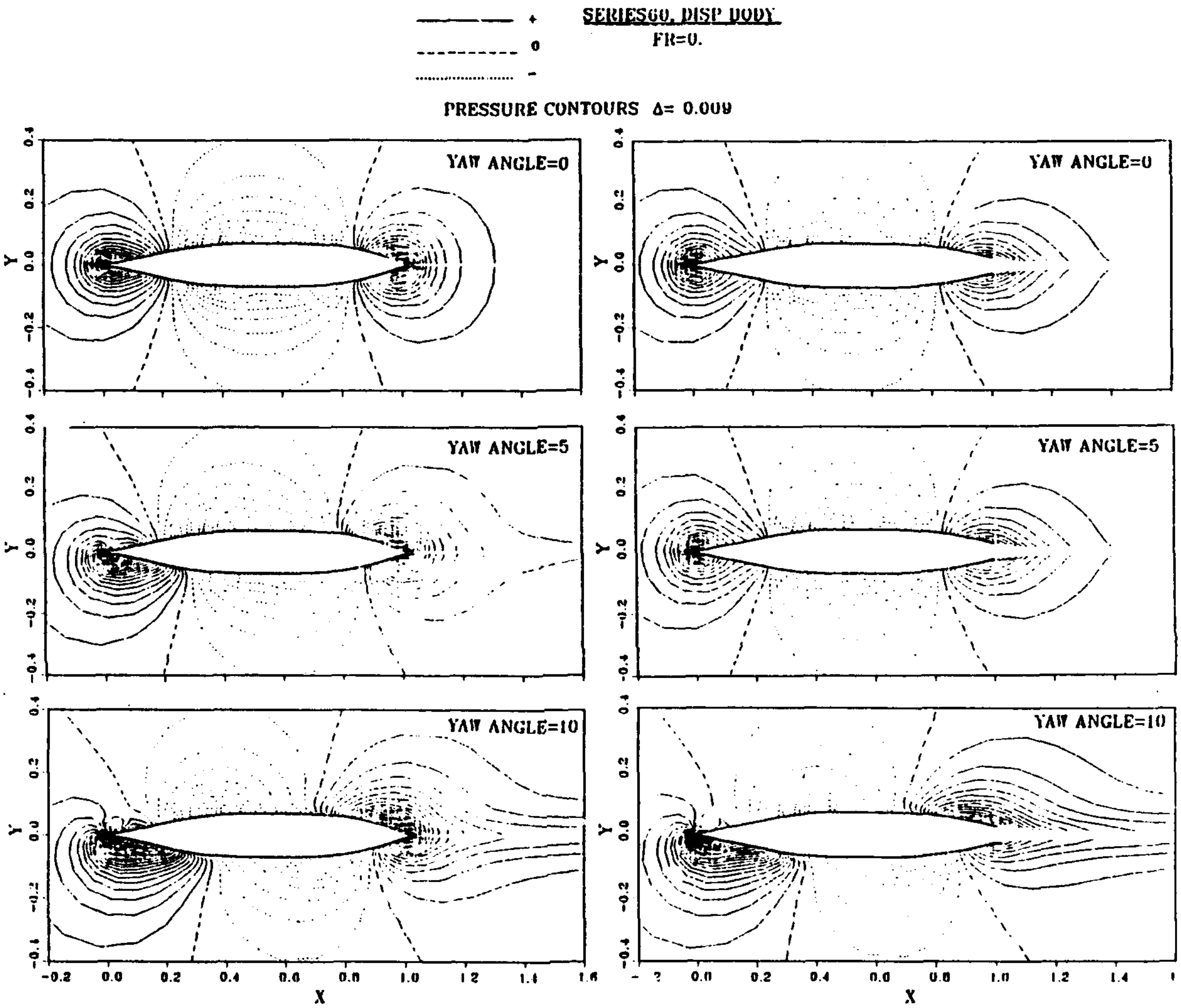


Figure 5 SPLASH Results for 0, 5, and 10 Degree Yaw : Fr = 0

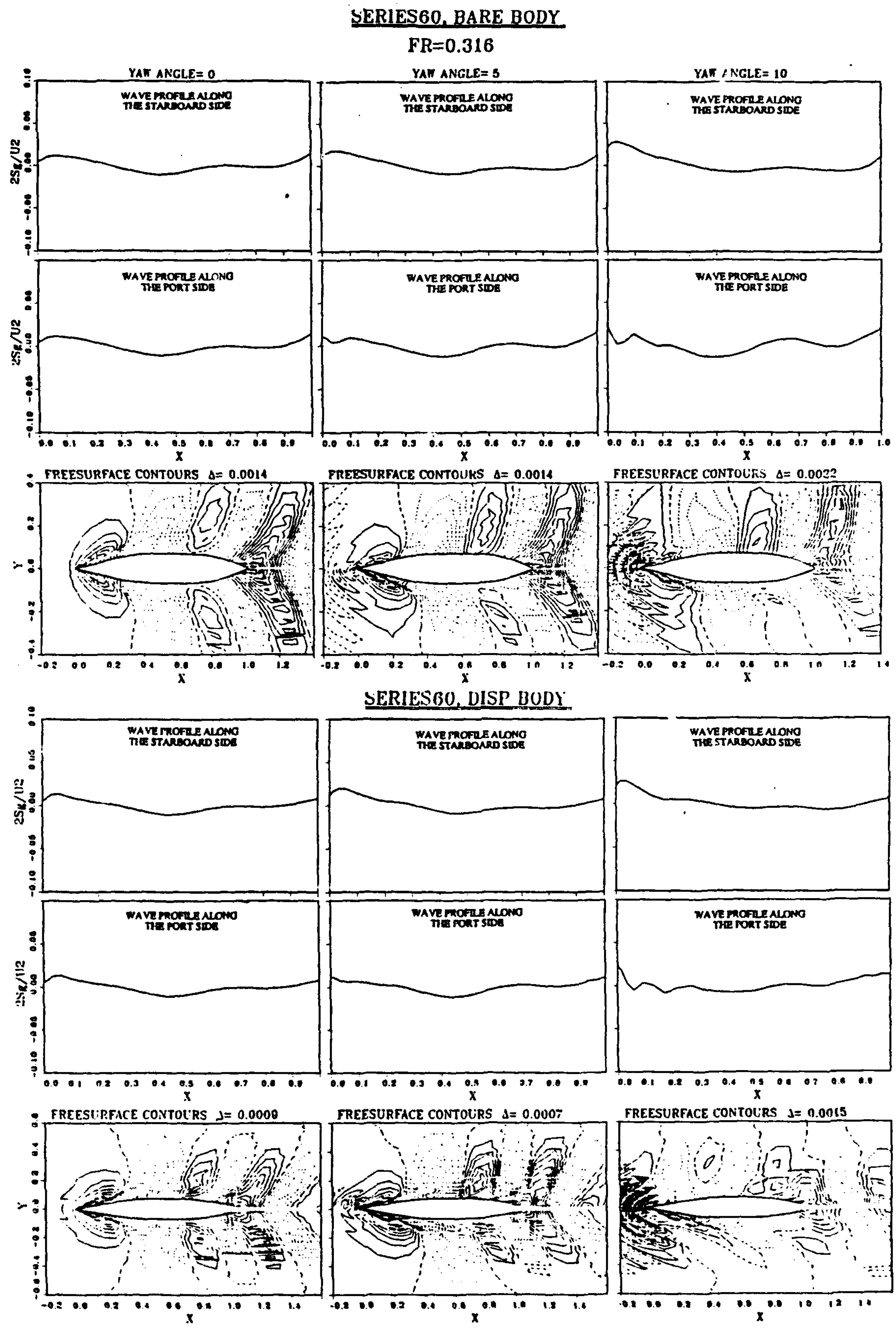


Figure 6 SPLASH Results for 0, 5, and 10 Degree Yaw : Fr = .316